Discussion of "Development of Laminated Bamboo Lumber: Review of Processing, Performance, and Economical Considerations" by M. Mahdavi, P. L. Clouston, and S. R. Arwade

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The authors provide a useful review of laminated bamboo lumber (LBL) as a structural building material. LBL in the original paper is a composite lumber made from bamboo, which has the mechanical properties of bamboo and can be manufactured in designed dimension similar to commercially available wood products. The original paper summarizes the physical and mechanical properties of bamboo at the beginning, and then the processing methods and mechanical properties of LBL are reported. The prospect of LBL being used as structural material is analyzed from an economic and environmental aspect. Based on experiences working in this important and emerging area, the discussers would like to add a few clarifications and introduce another important laminated bamboo that the authors did not review in detail.

Code and Standard Issues

The authors claim that there is no official recognition for bamboo as structural materials. Although there is no relevant code or standard in the United States, bamboo has gained access for use in building based on previous International Conference of Building Officials (ICBO) and current International Code Council (ICC) approval (AC162 2000), which was developed by Bamboo Technologies based in Hawaii. Internationally, the International Network of Bamboo and Rattans (INBAR) successfully sponsored the development of a model standard for the International Organization for Standardization (ISO) (ISO 22156 2004). In Latin America, bamboo or guadua bamboo has been widely used in dwellings for a long time. Colombia can probably be credited as the first country to implement the chapters for the design of guadua bamboo in the national codes for seismic design of structures (NSR-10 2010). All these documents are related to the design of buildings made with round bamboo.

Products and Manufacturing Processes

The authors seem to use LBL as a general technical term and reviewed several manufacturing processes, namely, Methods 1 to 3; however, only Method 2 shown in Figs. 4 and 5 of the original paper is one of the processes currently practiced in producing LBL, particularly higher quality products such as bamboo floorings and elements for bamboo furniture. This LBL is an excellent bamboo product; however, it has the drawback of being too expensive because of factors such as the stringent requirement for accuracy in producing the bamboo strips, certain waste of portions of bamboo sections, and limitations in length. The authors' reviews on cost and mechanical properties of LBL appear to be mainly based on this particular product; thus the conclusions regarding mechanical efficiency and cost of LBLs may not be fully adequate.

GluBam

The discussers have developed another type of LBL, or GluBam. The authors mentioned this new material in the original paper though without details. In Xiao et al. (2010b), two typical types of laminated bamboo are introduced—thick-layer laminated bamboo sheets and thin-layer laminated bamboo sheets. The thick-layer laminated bamboo sheets are made by pressure gluing a few layers of relatively thicker bamboo strips (Wahab et al. 2006). The-top-of-the-line products can make floor plates, which became available in the North American market recently. The LBL focused on in the original paper is actually a type of thick-layer laminated bamboo The thin-layer laminated bamboo sheets typically have a thickness of about 10 to 15 mm and are made by laminating approximately 2-mm-thick bamboo strip mats. They are mass-produced and widely used as concrete formwork in China. The thin-layer laminated bamboo sheets with thickness of about 30 mm are also produced in China for application as floors of containers, trucks or passenger buses, and trains.

The process of producing thin-layer laminated bamboo starts with cutting down and collecting the matured bamboo. The bamboo culms are then split to strips with a width of typically 20 mm. The strips are further sliced into thin strips with a thickness of about 2 to 3 mm. The strips are netted into unidirectional or weaved into bidirectional mats. These procedures can either be completed in the field or at simple facilities with simple machines or tools. The mats need to be boiled to protect them from rot. The mats are then cleaned and dried in a kiln. The dried mats are then saturated in phenol formaldehyde resin and dried again. The resin-saturated bamboo strip mats are finally stacked in a hydraulic pressure machine. The layout of the bamboo strip mats can be based on designs for desired fiber orientation composition for different applications. Several sheets can be pressed together under a pressure of about 20 MPa and a temperature of 150°C for 15 to 20 min. One of the major advantages leading to great cost efficiency of thin-layer lamination is the less stringent requirements of bamboo. Fig. 1 shows a worker unloading a batch of bamboo with wide variation in diameter to be processed for thin-layer lamination.

Based on extensive reviews of the existing bamboo products available in China and careful comparison of the costs and known properties, the first discusser's team has adopted the thin-layer laminated bamboo sheets to produce GluBam (Xiao et al. 2008, 2009). So far, the discussers' team has built five bridges with length ranging from 4 to 40 m in the provinces of Hunan and Guangdong, China, and completed several buildings with building areas of 100 to 250 m^2 in China and Africa (Xiao 2010a, b).

Fig.1. Typical batch of row bamboos collected for producing GluBam

Main Mechanical Properties of GluBam

The discussers have conducted a series of studies to quantify the mechanical properties of GluBam. Excellent results were obtained, which are shown in Table 1. As shown in Table 1, the mechanical properties including in-plane tensile and compressive strength, bending strength, and elastic modulus of GluBam are quite competitive compared with the data shown in Tables 1 to 3 in the original paper. A drawback of GluBam might be its relatively high density. However, the discussers have recently developed other products with reduced self-weight.

In short, the discussers believe that the LBL product, based on the thick-layer bamboo strip lamination reviewed by the authors, has several drawbacks and may not be the most suitable product for structural usage. Based on the testing results and demonstration projects conducted by the discussers' research team, the GluBam using thin-layer bamboo strip lamination appears to be more promising.

Table 1. Main Mechanical Properties of GluBam

Materials	In-plane compressive strength (MPa)	In-plane compressive strength (MPa)	Bending strength (MPa)	Elastic modulus (MPa)	Density (kg/m^3)
GluBam	51	82	99	10,400	720–880

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